The Evolution of Ingenuity Programs at the Lawrence Hall of Science

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ABSTRACT
Many science centers like the UC Berkeley Lawrence Hall of Science (the Hall) have been undergoing a transformation, adapting visitor program models from primarily exhibits and scheduled classes to active participation by public visitors who co-construct with rich materials and collaborate on design challenges. This trend in concert with the growing "Maker Movement" has also influenced the design of new public education programs, classes, and outreach programs, migrating into neighboring communities through partnerships. This paper details the origin and evolution of these engineering design-focused activities – the Ingenuity Programs – including its expansion at the Hall and its integration of local community resources. We also identify educational criteria for our Ingenuity Programs, as well as share lessons learned.

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1. INTRODUCTION
The Lawrence Hall of Science (the Hall), the public science center of the University of California, Berkeley, has been an active participant in the growing "Maker Movement" for many years, sharing in the goal of providing young people with inspiring project ideas as well as mentors to help them work on their own engineering, art, and science projects. The Hall's line of Ingenuity Programs seeks to inspire the next generation of innovators and engineers. Ingenuity Programs build on the best of "tinkering" and "maker" content in science centers, but emphasize the engineering design process and engineering careers.

The Hall's Ingenuity initiative started with the *Ingenuity Lab*, which was launched in 2009 as an experiment: a drop-in lab engaging visitors of all ages in fun, hands-on engineering design challenges, serving 15,000 visitors annually. Each month, the Lab offers a different open-ended design challenge, providing visitors with assorted low-cost materials and reusable electronics to construct solutions through various approaches and levels of complexity. As visitors go through the stages of iterative prototyping, they work collaboratively to solve real-world challenges (e.g., Wind Turbines, Solar Energy, and Hydraulics), guided by engineering students who volunteer their services and, in turn, increase their engineering skills. The success of the Ingenuity Lab has led to the creation and addition of many other programs by the Hall:

- *Ingenuity in Action* (opened 2010), a floor exhibit based on three of the *Ingenuity Lab*'s most successful challenges, hardened and scaffolded to require less facilitation.
- *Inventor's Lab* (opened 2011), a satellite site in Vallejo replicating the Hall's most popular Ingenuity Programs, including a new line of engineering design workshops for grades 3-8.
- *Ingenuity Lab Industry Partnerships* (implemented 2012-2013), a cross-community collaboration with local engineers and engineering students to design, develop, and implement Ingenuity Lab challenges.
- *Open Make* (hosted in Spring 2013), public events with thematic interactive hands-on activities and featured Maker presentations, including Young Makers, leading up to the Maker Faire in San Mateo.
- *Design Quest* (opened in Summer 2013), a 5000 square foot exhibition featuring an expansion of *Ingenuity in Action* and *Ingenuity Lab*.

This paper details the origin and evolution of the Ingenuity Programs at the Lawrence Hall of Science, identifies educational criteria for our programs, and provides lessons learned.

2. PROGRAM GOALS
The mission of the Lawrence Hall of Science is to inspire and foster learning of science and mathematics for all, especially those who have limited access to science. The Hall's *Ingenuity* initiative was initially inspired by the popularity of the Hall's simple building block exhibit, where visitors have access to 10,000 identically milled pine planks to build whatever structures they desire. When temporarily removing the exhibit resulted in huge visitor outcry, the staff examined both the extensive hold time and the cross-generational collaboration the exhibit inspired. This coincided with the rise of the Maker Movement in the San

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Francisco Bay Area and in the science center field, and with several Hall staff members returning from Playful Invention and Exploration (PIE) Network trainings and visits to the Weston Family Innovation Pavilion at the Ontario Science Center. The *Ingenuity Lab* was then developed as a pilot program to implement these novel museum interactions. Based on visitor attendance, the program was judged to be highly successful, but through closer evaluation of the program, researchers found that while the program engaged visitors for long times, visitors had difficulty identifying engineering relevance. As a result, the Hall modified the program to incorporate the learning of engineering design and engineering careers into the Ingenuity Programs.

The goals of the Ingenuity Programs are to:

- Foster lifelong love of learning
- Raise the next generation of innovators
- Excite interest in STEM and related careers
- Develop 21st century learning skills
- Create immersive experiences that appeal to and engage audiences of diverse backgrounds and ages
- Provide an open-ended and personalizable experience
- Promote intergenerational collaboration
- Expose visitors to engineering design through the hands-on process of iterative prototyping
- Prompt visitors to embrace risk and failure
- Instill creative confidence

3. ITERATIONS IN VARIOUS SETTINGS

Beginning with the Ingenuity Lab in the Fall of 2009, the Ingenuity Programs have continued to expand to a variety of settings and formats. The goals of the Ingenuity Lab above have helped us shape the program to be accessible and engaging for a variety of ages and backgrounds. Through changes in materials, youth roles, program structure, or environment set-up, we have also scaled the making and engineering design experiences for varying levels of complexity.

Facilitators scaffolding the experience are a key component of the Ingenuity Programs. To support the Hall's permanent staff, we have recruited and trained members of the local community, including college student staff, volunteers (both adult and teenage), teen interns, and college engineering students from Berkeley Engineers and Mentors (BEAM).

3.1 Ingenuity Lab Drop-in Program

The Ingenuity Lab is open to the public on a drop-in basis during weekends, providing engineering design challenges to about 800 visitors each month, with positions in life ranging from toddler to elderly. The majority of children who visit are between the ages of three and twelve, usually consisting of approximately even numbers of boys and girls. Most visitors come as families and collaborate together across generations. Because the program was an early experiment in program design, it was held in a large classroom space downstairs from the main exhibition halls, allowing visitors to come and go as they wish with the average stay time just over 30 minutes. Past challenges have included the use of sticks, rubber bands, wires, tubes, string, and sponges to create grabbers to pick up objects (i.e., mechanical grabbers) and of motors, batteries, glue sticks, cardboard, tubes, and markers to make vibrating machines that draw patterns (i.e., scribble machines).

Throughout the history of the Ingenuity Lab, the Hall has also collaborated with various groups from the University of California, Berkeley's College of Engineering and local industry engineers to develop design challenges about current research and industry topics. In Fall 2010 and Spring 2011, students from a first-year introduction to engineering course participated in five-week modules to research, design, and develop challenges or facilitation techniques to engage visitors in engineering design. In Fall 2012 and Spring 2013, two groups of students collaborated with local engineers to design, develop, and implement a challenge based on the engineers' work. One team of students from BEAM collaborated with two Google engineers, and another team of students from a product development engineering course collaborated with two engineers from an industry partner, Meyer Sound. During the same period, educators from the Ingenuity Lab collaborated with scientists and engineers from ReNUWIt, a National Science Foundation-supported Engineering Research Center for Re-inventing the Nation's Urban Water Infrastructure, to develop a challenge representing their research.

Figure 1. Family designing and building rockets at the Ingenuity Lab.

3.2 Ingenuity in Action Exhibit

Following the refinements and success of the Ingenuity Lab, the program migrated to the public floor as the Ingenuity in Action exhibit in Summer 2010. It consists of the three most successful Ingenuity Lab challenges: creating designs for a wind tube (Fly High), modifying variables for motorized LEGO cars (Design and Drive), and building bridges to span a gap and support a weight (Build a Bridge).

3.3 Inventor's Lab

The Inventor's Lab was the first satellite experiment in May 2011 to extend the Ingenuity Lab into an underserved community (Vallejo, Solano County) to inspire and prepare youth to do science and mathematics. Funding from the Gordon and Betty Moore Foundation allowed the Hall to replicate our line of Ingenuity Programs to this region that was not being reached by the five largest science centers in the San Francisco Bay Area. The Ingenuity Lab and Ingenuity in Action exhibits were chosen as the core programming for the satellite site because of its interactivity, adaptability across age groups, and repeatable nature. The Vallejo expansion project experimented specifically with making the Ingenuity Lab experience portable and available to school and community groups for field trips. Program offerings included hands-on exhibits, classroom workshops, collaborations with afterschool programs, and professional development for out-of-school educators to provide them the tools and resources to bring science into their programs.

3.4 Design Quest Exhibition

In the Summer of 2013, the Hall launched a new exhibition called Design Quest, which embedded key elements of the Ingenuity Programs. Hands-on activities were "hardened" as interactive exhibits including the three activities from Ingenuity in Action. The Ingenuity Lab temporarily relocated to the exhibit floor and, under its new name Ingenuity Studio, offered daily engineering design challenges and invited Makers from the community to design, build, test, reflect, and share their passions. Challenges include Turbines, Hydraulics, Marble Machines, Circuits, MaKey Makey, Cardboard Arcades, Bike Sim, Prosthetics, and others.

Figure 2. Kids collaborating on the design of a hydraulic claw at Design Quest.

The Design Quest exhibition has also provided an opportunity to collaborate with the TechHive Learning Lab program, a design internship program under development in which teens engage in projects that apply the engineering design and fabrication processes mediated by various cutting tools and online design and programming environments. The collaboration benefits both the Ingenuity Programs and the TechHive: the Ingenuity Programs serve as a client for the TechHive teens who design projects and practice communicating to the public, while the TechHive is a resource for Design Quest to enrich its programs with technology. Thus, this reciprocity provided a win-win opportunity for both design-oriented programs.

3.5 Other Programs

3.5.1 Involvement with the Maker Movement

Because the institution already embraced the notion of co-construction with the public, the Lawrence Hall of Science further engaged in program experimentation serving as the East Bay host site for Open Make, four monthly events highlighting the tools, techniques, and ingenuity of local Makers that led up to the Maker Faire. Partners from the UC Berkeley campus and the Maker community were invited to share resources, give talks, and facilitate various interactive hands-on activities throughout the day. The Open Make event also served as a regional meeting session for the local Young Makers, attracting older youth to the Hall.

3.5.2 Camps and Classes

The line of Ingenuity Programs has also been a catalyst for new workshops and camps to the Hall's offerings for the school and family audience i.e., *Hydraulics* workshop (grades 3-8), *Turbines* workshop (grades 3-8), *Young Tinkerers Camp* (ages 4-5), *Build it Up-Take it Apart* (grades 5-7), and *Animation Camp* (grades 5-7).

4. PROGRAM DESIGN CRITERIA

Through the various iterations and evolution of the Ingenuity Programs over the years, our list of criteria for effective activities has been refined. The development of an effective engineering design challenge is informed by the following.

4.1 Environment and Materials

- Learning environment supports creativity and independence
- Sample designs seed ideas and inspiration
- Functional and flexible space and set-up suggest individual initiative and autonomy with easy-to-access stations and materials, as well as floating facilitators to help as needed
- Station design encourages collaboration and cross-pollination
- Basic and common building materials show that science can be done anywhere
- Technology is used as a building block

4.2 Design Criteria

- **"Low Floors, High Ceilings, and Wide Walls"** [3]: The challenge has low entry points for all learners to get started quickly, plenty of room to grow competencies and fluency in knowledge and skills, and an open context for broad and diverse design solutions.
- **Open-ended:** Design challenges are open-ended, allowing for various degrees of complexity, inviting both boys and girls to construct their own narratives.
- **Multiple Goals & Solutions:** As a helpful learning design constraint**,** the challenge offers visitors the option of choosing their goal (e.g., a turbine that lifts a weight or a turbine that creates electricity) or asks visitors to balance competing goals (e.g., cheap vs. fast, strong vs. light). Each challenge should allow for several design solutions that can satisfy the goals of the challenge.
- **Testable:** The success of the design can be measured using reliable, non-subjective tests.
- **Real World Context:** The challenge is framed in a meaningful real-world engineering context.
- **Short Iteration Time:** The design can be developed and tested quickly to allow for multiple iterations of improvement.
- **Noticeable Improvement:** It is possible to achieve noticeable, measurable improvement by refining the design.
- **Take-Home Component:** With visitor consent, we take pictures in the lab that upload to a public Flickr account.
- **Gender Neutral and Appealing to All Ages:** The challenge, materials and context are appealing to both boys and girls. There are also various levels of difficulty for different ages.

5. FACILITATION

Facilitation is key to the visitor experiences at the Ingenuity Programs. The most common comment from visitors is how much they enjoyed working with the facilitators (both staff, college students, and adult volunteers), especially the helpfulness of the facilitators. Thus, extensive training and ongoing coaching is key to a successful experience for both visitors and facilitators. Important guidelines for our facilitators are:

- Be welcoming and spark interest
- Follow the visitor's path, assisting as needed
- Strengthen understanding and clarify intentions through reflective conversation
- Draw attention to engineering design methodology and make explicit connections between the action of participants and the work of professional engineers through guiding questions
- Help visitors to embrace failure!

6. EVALUATION

Ongoing evaluation and research of our programs provides insight into how we can improve the visitor experience. We have a short computer-based post-experience survey that visitors voluntarily take, which includes questions on the children's gender and age, their favorite part, what surprised them, how they felt the activity was related to engineering, their previous experiences in making, and their future intentions in making. So far, over 700 survey responses have been collected. Responses indicate that visitors especially valued facilitation from staff and volunteers; families engaged in and recognized their own engineering behaviors through the refinement of their design solutions, perceiving engineering as accessible; and many parents hoped to pursue such activities at home and return to the space [5]. We also have a time tracking system that our staff and volunteers use to obtain the total number of visitors as well as the average stay-time, with an average of 118 visitors per day, staying over 32 minutes. The average stay-time is calculated with a simple one-box model [2]; samples of the number of visitors in the room and the number who left are taken every 5 minutes. More in-depth research has been conducted through observations and interviews of visitor groups at these programs as well as studies of students developing content for the Ingenuity Programs (see references [1,4-9]).

7. LESSONS LEARNED

From the beginning of the first Ingenuity Lab challenge, through its evolution into various forms in various settings, we share the lessons learned thus far: (1) Developing and prototyping new programs for a cross-generational audience with continual feedback from visitors has proven to be a successful strategy to attract repeat visitors to the Hall while gaining information about ways to refine the program. (2) By aiming to design for various ages and backgrounds, successful design challenges can easily be modified for specific age groups and various settings. (3) New and innovative learning environments and programs like maker spaces need to start small, be crafted and improved through iterative evaluation, and demonstrated to be successful before being embraced by staff and the leadership team to get the institutional buy-in and support needed for further growth and success. (4) Taking advantage of local resources provides a step towards a sustainable means to continue developing new content through collaborations with the community. (5) Collaboration with students and industry professionals can be challenging because of time and scheduling constraints. (6) Good facilitation is key to a good visitor experience.

8. CONCLUSION

The Ingenuity Programs at the Lawrence Hall of Science are a novel approach to align the "Maker Movement" with educational goals in the fields of mathematics, science, engineering, and technology. The success of the line of Ingenuity Programs has led to a shift in the museum institutional culture. Visitors have not only returned multiple times for the Ingenuity Programs, but many have become members of the museum. The Hall's line of programs can be easily adapted and mark a promising step towards meeting the Next Generation Science Standards (NGSS) in the United States. Ingenuity Programs have been embraced by the Hall leadership team and were identified as one of the most successful and established public programs in the Hall's strategic planning process. The Hall's future plans include expanded support of these programs.

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